Flood Frequency Analysis of River Subernarekha, India, Using Gumbel's Extreme Value Distribution

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ABSTRACT

Estimation of Peak Flood Discharge for a desired return period is a pre-requisite for planning, design and management of hydraulic structures like barrages, dams, spillways, bridges etc. In this paper, a mathematical model has been developed between Peak Flood Discharge and Return Period using Gumbel's Extreme Value Distribution. The model will give reasonable estimate of Peak Flood discharge for any desired value of T, without any instrumentation and expensive and time consuming field work. Peak Discharge is a potential tool for designing important hydraulic structures like Concrete Gravity Dam, Weir, Barrage, and Bridge across the river, Guide bank etc. Moreover, the Stage corresponding to any given value of Peak Discharge can readily be ascertained by developing Rating Curves following the procedure given by the Author as referenced below. This Stage will be helpful in maintaining Danger Level Flood of the river Subernarekha. Emergency evacuation may be adopted by propagating well advanced 'Flood Warning' that may save thousands of lives from the fury of flood, may be put in place.

KEY WORDS: *River Subernarekha, Peak Flood Discharge, Return Period, Gumbel's Extreme Value Distribution, Confidence Limit, Stage. Chi-Square test.*

I. INTRODUCTION:

Estimation of Peak Flood Magnitude for a desired return period is often required for planning, design and management of hydraulic and other structures in a region. These events are essential in the post commissioning stage where in the assessment of failure of hydraulic structures needs to be carried out. (Wyno Journal of Engineering & Technology Research, Vol. 1(1) PP- 1-9 March, 2013). In this paper, 6-h unit hydrograph data is used for Peak Flood Estimation to arrive at a design parameter for a region. In extreme value theory, probability distribution of Gumbel is widely used for frequency analysis of recorded meteorological data such as rainfall, temperature, wind speed, evaporation, Peak Flood etc and hence used in the present studyThe Subernarekha [http:\\www.springerlink.com/ content/7885062173413017/] is an inter-state river flowing through Bihar, West Bengal and Orissa states. It starts in the Chotanagpur Plateau of Bihar and flows into the Bay of Bengal. The upper part of the Subernarekha and its tributaries run through the fertile land of Bihar, but the farming in this region mainly depends on the inadequate and ultimate rains, and the water resources of the Subernarekha river system remain largely untapped. The upper basin, besides containing fertile land, also contains large reserves of minerals. A number of important industries have therefore grown along the banks of the river.

Subernarekha Multipurpose Project is a joint project of Jharkhand, Orissa and West Bengal state for which tripartite agreement was signed between undivided Bihar, Orissa and West Bengal on 07.08.1978. The benefits of the project is furnished hereunder-

a) JHARKHAND:
   - i) The creation of Irrigation Potential - 2, 36,846 ha.
   - ii) Municipal and Industrial Use - 740 MCM annually
   - iii) Hydel Power Production - 8 MW

b) ORISSA:
   - i) Creation of Irrigation Potential - 90,000 ha

c) WEST BENGAL:
   - i) Creation of Irrigation Potential - 5,000 ha

Catchment characteristics such as, stream order, drainage density, stream density, length, shape, slope, etc., [Reddy, J, R., 1998] and Annual Peak Flood Magnitude were not available. Instead, one 6-h unit hydrograph for Kharkai Barrage Site was used for the present study (Data Source: Irrigation International Building, Salt Lake City, Kolkata, Government of West Bengal, India).

II. PROCESSING OF THE COMPUTER OUTPUT DATA

By using the method of superposition, the unit hydrographs of different durations have been obtained. In this method, if a D-hour unit hydrograph is available, and it is desired to develop a unit hydrograph of nD-hour duration, where n is an integer, it is easily accomplished by superposing n unit hydrographs with each graph separated from the previous one by D-hour [Subramanya, K, 1994]. A Computer Program has been developed for this purpose. First of all, from the computer output, the unit hydrograph for each duration of Kharkai Catchment has been developed. Then from the unit hydrograph thus developed, the Peak Discharge (Q_p) and corresponding D have been identified. Before use, the data has been statistically checked for consistency and continuity.

III. GUMBEL DISTRIBUTION

Gumbel distribution is a statistical method often used for predicting extreme hydrological events such as floods (Zelenhasic, 1970; Haan, 1977; Shaw, 1983). In this study it has been applied for flood frequency analysis because (a) peak flow data are homogeneous and independent hence lack long-term trends; (b) the river is less regulated, hence is not significantly affected by reservoir operations, diversions or urbanization; and (c) flow data cover a relatively long record and is of good quality (Mujere, 2006). (IJCSE-ISSN: 0975-3397, Vol. 3 No. 7 July 2011). The equation for fitting the Gumbel distribution to observed series of flood flows at different return periods T is (Sarma, 1999).

$$X_T = \overline{X} + K.\sigma_{n-1} \quad \ldots\ldots\ldots\ldots \quad (1)$$

Where, X_T denotes the magnitude of the T- year flood event, K is the frequency factor; ẋ and σ_{n-1} are the mean and the standard deviation of the maximum instantaneous flows respectively.

The reduced variate is expressed as $y_T = -[\ln.\ln.(T/T-1)]$…… (2)

The frequency factor expresses as $K = (y_T - y_n)/s_n$ …………………….. (3)

Where, y_n and s_n are taken from, standard Table of (K Subramanya, 2004).

The Chi-square ($\chi 2$) test was carried out to find goodness of fit between the measured and predicted flood flows. It was applied to test the hypothesis that the flood data fit Gumbel distribution. Details of Chi-square ($\chi 2$) test has been furnished in Table-4 her under.

The detailed Computation table and the model in graphical & equation form are furnished here under.

Table showing computation details by Gumbel's Extreme – Value distribution

Table-1

Peak Flood Discharge (Qp) in Cumec (Field Value)	Sample Size, N	Mean of Series, $\overline{X}$, in Cumec	STDEV of the Series, $\sigma_{(N-1)}$, in Cumec	Return period T in Years	Reduced Variate, y_T	Frequency Factor, K	Computed Peak Flood Discharge X_T in Cumec obtained by Gumbel's method
862.00	100	104.93	140.0465	2.5	0.67172	0.09	117.53
657.50				5	1.49999	0.78	214.17
574.67				7.5	1.94420	1.14	264.58
502.50				10	2.25037	1.40	300.99
439.80				12.5	2.48432	1.59	327.60
388.00				15	2.67375	1.75	350.01
346.14				17.5	2.83292	1.88	368.21
313.37				20	2.97019	1.99	383.62
284.22				22.5	3.09087	20.9	397.62
258.80				25	3.19853	2.18	410.23
236.10				27.5	3.29572	2.40	421.43
216.42				30	3.38429	2.34	432.64
199.77				32.5	3.46565	2.40	4410.4
185.50				35	3.54088	2.47	45.084
173.13				37.5	3.61085	2.52	457.84
162.31				40	3.67624	2.58	466.25
152.76				42.5	3.73762	2.63	473.25

144.28				45	3.7945	2.68	480.25
136.68				47.5	3.85010	2.72	485.85
129.85				50	3.90193	2.77	491.45
123.67				52.5	3.95121	2.81	498.46
118.04				55	3.99817	2.85	504.06
112.91				57.5	4.04302	2.88	508.26
108.20				60	4.08595	2.92	513.86
103.88				62.5	4.12711	2.95	518.06
99.88				65	4.16664	2.98	522.26
96.18				67.5	4.20467	3.02	527.87
92.75				70	4.24131	3.05	532.07
89.55				72.5	4.27665	3.08	536.27
86.57				75	4.31078	3.10	539.07
83.77				77.5	4.34379	3.13	543.27
81.16				80	4.37544	3.16	547.47
78.70				82.5	4.40670	3.18	550.27
76.38				85	4.43674	3.21	554.47
75.20				87.5	4.46589	3.23	557.28
72.13				90	4.49422	3.26	561.48
70.19				92.5	4.52177	3.28	564.28
68.34				95	4.54859	3.30	567.08
66.59				97.5	4.57470	3.32	569.88
64.92				100	4.60014	3.34	572.68

Developed model is furnished here under:

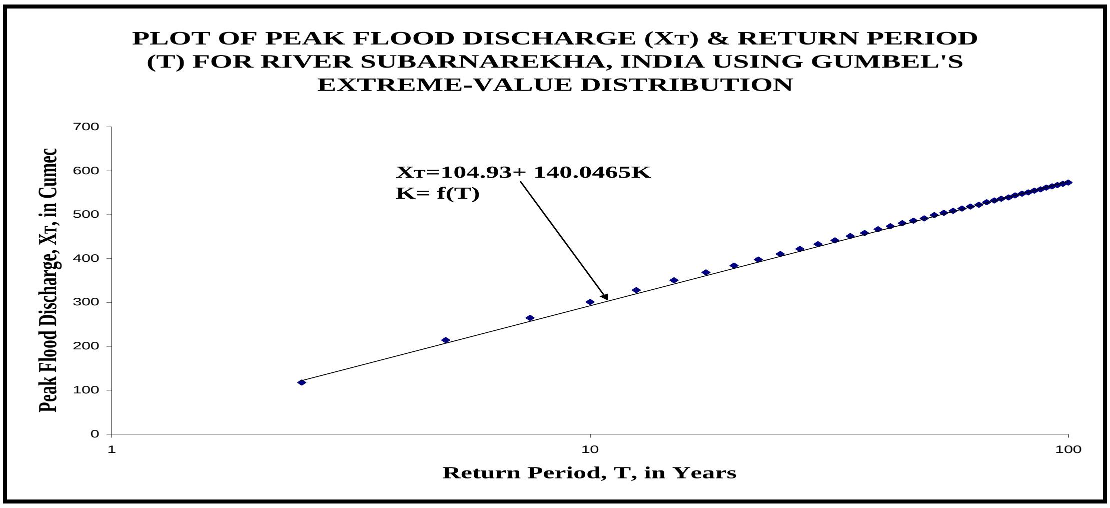

Figure-1

Confidence limit:

Table:2

Sample N	Mean of Series	STDEV of Series	Return period T in Years	Frequency factor K	Upper bound value of Peak flood discharge, X2 in Cumec	Peak flood discharge, X-T computed by Gumbel's method in Cumec	Lower bound value of Peak flood discharge, X-1 in Cumec
100	104.93	140.0465	2.5	0.09	146.643	117.53	88.416
			5	0.78	287.80	214.17	140.53
			7.5	1.14	371.91	264.58	157.25
			10	1.40	437.53	300.99	164.45
			12.5	1.59	488.06	327.60	167.137
			15	1.75	517.88	350.01	167.705
			17.5	1.88	569.88	368.21	167.54

	20	1.99	601.57	383.62	165.61
	22.5	2.09	631.49	397.62	163.75
	25	2.18	658.86	410.23	161.59
	27.5	2.26	683.65	421.43	159.21
	30	2.34	708.68	432.64	156.59
	32.5	2.40	727.95	441.04	154.13
	35	2.47	750.524	450.84	151.156
	37.5	2.52	766.84	457.84	148.84
	40	2.58	786.64	466.25	145.86
	42.5	2.63	806.01	473.25	140.48
	45	2.68	820.06	480.25	140.43
	47.5	2.72	833.85	485.85	138.07
	50	2.77	849.29	491.45	133.60
	52.5	2.81	864.50	498.46	132.41
	55	2.85	878.34	504.06	129.78
	57.5	2.88	888.57	508.26	127.94
	60	2.92	902.822	513.86	124.90
	62.5	2.95	913.196	518.06	122.924
	65	2.98	923.98	522.26	120.54
	67.5	3.02	938.37	527.87	117.36
	70	3.05	949.07	532.07	115.06
	72.5	3.08	959.94	536.27	112.59
	75	3.10	967.16	539.07	110.98
	77.5	3.13	978.05	543.27	108.48
	80	3.16	989.03	547.47	105.90
	82.5	3.18	996.36	550.27	104.18
	85	3.21	1007.23	554.47	101.71
	87.5	3.23	1014.84	557.28	99.718
	90	3.26	1026.04	561.48	96.92
	92.5	3.28	1033.504	564.28	95.056
	95	3.30	1040.96	567.08	93.20
	97.5	3.32	1048.43	569.88	91.326
	100	3.34	1056.10	572.68	89.66

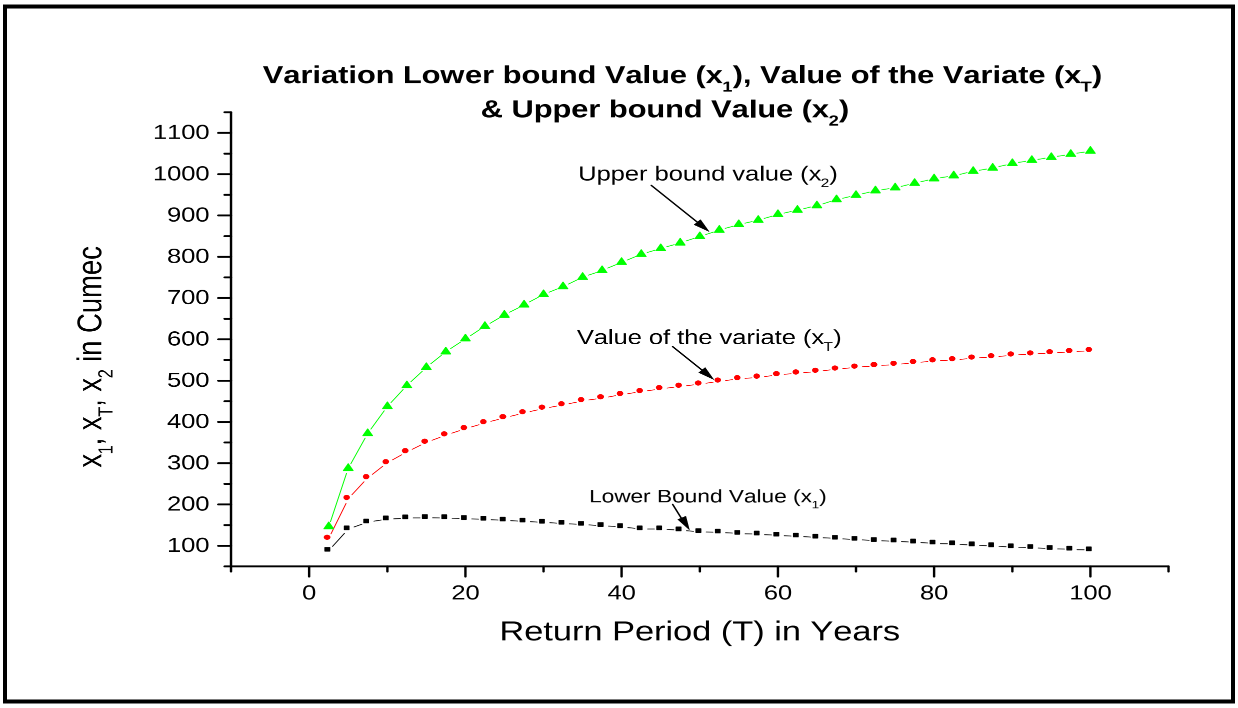

Figure-2

Table Showing Comparison of Peak Flood Discharge Computation by Gumbel's Extreme Value Distribution and Empirical Model developed by Author Referenced in the following Table 3

Table-3

Return Periods T in Years	Peak Flood Discharge X_T (Cumec) Computed by Gumbel's Method	Peak Flood Discharge Qp (Cumec) Computed by Empirical Model developed by the Author(IJCR Vol-4, Issue,04, pp-164, April, 2012)	% Deviation	Absolute % Deviation	Average of Absolute % Deviation	Remarks
2.5	117.53	66.12	43.74	43.74	14.75	Hence, it can be concluded that the Peak Flood Discharge computed by the aforesaid two methods are reasonably close to each other. But, obviously model obtained from Gumbel's Method is more accurate to some extent because it is a pure statistical extreme-
5	214.17	128.68	39.86	39.86		
7.5	264.58	186.10	29.66	29.66		
10	300.99	238.60	20.72	20.72		
12.5	327.60	286.39	12.57	12.57		
15	350.01	329.68	5.83	5.83		
17.5	368.21	368.71	-0.13	0.13		
20	383.62	403.67	-5.22	5.22		
22.5	397.62	411.49	-3.488	3.488		
25	410.23	462.27	-12.68	12.68		
27.5	421.43	486.34	-15.40	15.40		
30	432.64	507.22	-17.23	17.23		
32.5	441.04	525.11	-19.06	19.06		
35	450.84	540.23	-19.83	19.83		
37.5	457.84	552.81	-20.74	20.74		
40	466.25	563.05	-20.76	20.76		
42.5	473.25	571.17	-20.70	20.70		
45	480.25	577.38	-20.22	20.22		
47.5	485.85	581.90	-20.93	20.93		
50	491.45	584.96	-19.02	19.02		
52.5	498.46	586.75	-17.70	17.70		
55	504.06	587.50	-16.55	16.55		
57.5	508.26	587.43	-15.58	15.58		
60	513.86	586.75	-14.18	14.18		

62.5	518.06	585.57	-13.03	13.03		value distribution method.
65	522.26	584.41	-11.9	11.9		
67.5	527.87	583.79	-10.48	10.48		
70	532.07	582.22	-9.49	9.49		
72.5	536.27	581.71	-8.47	8.47		
75	539.07	581.89	-7.94	7.94		
77.5	543.27	582.97	-7.3	7.3		
80	547.47	585.17	-6.88	6.88		
82.5	550.27	588.69	-6.98	6.98		
85	554.47	593.76	-7.08	7.08		
87.5	557.28	600.59	-7.77	7.77		
90	561.48	609.40	-8.53	8.53		
92.5	564.28	620.40	-9.94	9.94		
95	567.08	633.80	-11.76	11.76		
97.5	569.88	649.84	-14.03	14.03		
100	572.68	668.71	-16.77	16.77		

Goodness of fit:

Table – 4

Summary of $\chi 2$ Test Results for the river Subernarekha

River	$\chi 2$ (Computed)	D.O.F	$\chi 2$ from Table		Remarks
			95% Confidence	99% Confidence	
Subernarekha	9.219	4	9.49	13.28	Passed at 95 % and 99% confidence

(Source: $\chi 2$ from Table: *N. G. Das, 1996; Table-I & II)*

IV. DISCUSSION

[1] It has already been established that Value of the Variate X_T is unbounded. Figure-2 shown above strongly supports this statement. Here, variation of X_1, X_T and X_2 with T are truly convergent in nature.

[2] Moreover, the author has developed an empirical model between Peak Flood Discharge (Q_p) .vs. Return Period (T), (IJCR, Vol-4, Issue, 04, pp-164, April, 2012). That empirical model has been compared with the model developed here by Gumbel's method and the comparison has been furnished in Table-3.

[3] It has been observed that the Peak Flood Discharge for a given Return Period (T) computed by two models mentioned above do not vary too much.

[4] 4. For a given Return Period (T), Peak Discharge can be computed by any of the two models, particularly at higher values of Return Period (T).

V. CONCLUSION

- For any anticipated T, X_T can readily be estimated from the developed model as shown in the Figure-1 and corresponding equation has also been furnished there.
- However, the model will give reasonable estimate of X_T for any desired value of T, without any instrumentation and expensive and time consuming field work.
- For any anticipated value of T, X_T can readily be ascertained from the developed model suggested above and the Stage (G), corresponding to X_T can be estimated following the procedure as given by [Mukherjee, M,K., and Sarkar, S., 2007].
- These Stages may be obtained from Stage-Discharge (G-Q) model, corresponding to X_T Therefore, the values of G thus obtained are on conservative side.
- If presently adopted Danger level for 'Flood' for the river Subernarekha at the gauging site, is lower than the stage computed from (G-Q) model, then there is no problem.
- If presently adopted Danger level for 'Flood' for the river Subernarekha at the gauging site, is higher than the stage computed from (G-Q) model, then the presently adopted danger level for flood needed to be changed.
- Therefore, emergency evacuation may be adopted by propagating well advanced 'Flood Warning' that may save thousands of lives from the fury of flood, may be put in place.
- 'Flood Plain Zoning' may also be introduced to protect the lives of thousands of people and their properties, to minimize the socio-economic disaster created by flood.
- Moreover, Peak Discharge (X_T) is a potential tool for designing important hydraulic structures like Concrete Gravity Dam, Weir, Barrage, Bridge across the river, Guide bank etc.
- The entire water resource of river Subernarekha is largely untapped. Hence, construction of hydraulic structures will be helpful for resource generation also.

IV. NOTATIONS USED IN THE PAPER

- **G** - Stage
- **Q** - Discharge
- **Q_p** - Peak Discharge of Unit Hydrograph
- **T** - Return Period
- **X_T** - Gumbel's Variate for a return period T
- $\overline{X}$ - Mean of the series
- **N** - Sample Size
- **P** - Probability of an event equaled to or exceeded
- **STDEV** - Standard Deviation of percentage deviation
- **X_1** - Lower bound value of X_T
- **X_2** - Upper bound value of X_T
- $\chi 2$ - Chi-Square

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